Chapter 4:

Measuring grazing treatment effects on upland plant communities

4.0 SUMMARY

The impact of the three systems-scale grazing regimes in the HSNW project on sward structure (height and vertical distribution of bryophytes, litter and live and dead vascular plant material) and species abundance was monitored in four plant communities. The grazing regimes were: continued year-round grazing; change to off-wintering; change to zero grazing. The plant communities were M17, U5, CG11 and U7, but only the U5 community occurred in all three grazing regimes, so results focus on this community. The method used consisted of 80 single-pin point quadrats distributed along four 20 m transects per community, recorded on at least two occasions, once before the grazing regimes were implemented and once 2-3 years later. A power analysis showed that the methods used were capable of detecting a change in height of 2.9 to 4.8 cm, depending on the variability of the sward. There was a significant interaction between height and treatment only for the ungrazed U5 community, where the sward increased from18.5 to 23.0 cm. To detect a change in mean height of 2.5 cm, 284 point quadrats would be required. A comparison of the level of within-observer variability in assessments of species abundance was made for two methods, point quadrats and visual estimates of small quadrats. This demonstrated that within observer variability for point quadrats was much greater than for visual quadrats.

Differences between observers obscured any changes that may have occurred in the amount of dead standing material present. The ungrazed sward became taller and less dense at the base, the off-wintered regime became slightly taller and more dense at the base, and the year-round grazed regime stayed the same height but became more dense at the base.

Changes in species abundance were also possibly affected by observer differences. A PCA of species abundance at the transect level showed that there were differences between species composition in the three regimes at the baseline monitoring, and that all transects moved in a similar direction. Power analysis of the point quadrat method showed that it would have been possible to detect a change of 15 % in the common species.

A monitoring regime with well-defined objectives is proposed, using the HFRO sward stick to record sward height and top cover of live and dead material, and visual estimates of small quadrats to record species abundance.

4.1 INTRODUCTION

Sheep grazing management regimes in the uplands are changed in response to economic and environmental pressures on farming (Watson, 1932; Barlow, 1985; Morgan Davies *et al.* 2000). Traditional management practice in Scotland over the last 200 years has involved leaving ewes on the hill throughout the year (Waterhouse, 1999), but other options include seasonal treatments where ewes are removed from hill ground for considerable parts of the year (Hulbert *et al.* 1999; Harris & Jones, 1998). Off-wintering, when pasture production on higher land is limiting (Eadie & Black, 1968; Vavra, 1985), allows the production of more and better quality lamb (Waterhouse *et al*. 2002).

The HSNW project (section 2.2) lent itself to the study of the impacts of three grazing treatments on sward structure and species abundance: i) continued year-round grazing by sheep; ii) the change from year-round grazing to off-wintering; iii) the change from year-round to zero grazing by sheep. The experimental design and monitoring methods of the study were determined by I.A.R. Hulbert in 1998. Baseline data were collected by J.P. Holland in summer 1998 before the start of the treatments, and the methodology was inherited by the author in Autumn 1999.

Understanding the impact of seasonal grazing management on sward structure and sward species abundance is critical since it influences both plant and invertebrate diversity and abundance (Dennis *et al*. 1995) and herbivore diet (Eadie & Black, 1968; Grant & Maxwell, 1988). These factors then have knock-on effects on the sustainability of the whole system, defined as long-term social and economic viability (Waterhouse *et al.* 2002). Complete removal of sheep from upland plant communities is known to have considerable impacts on sward height and quantity of litter (Hope *et al*. 1996; Marrs *et al*. 1988; Ball, 1974), but there is limited information on the impacts on upland grasslands of removing sheep during the winter months (Hill *et al.* 1992).

Sward structure was defined in this study in terms of height, and the amount and vertical distribution of sward components (live leaf, dead standing, stem and flower material, litter and bryophytes). It is affected primarily by the interaction between rates of growth, senescence and decomposition of the component species, and offtake by grazing animals (Chapman & Lemaire, 1993). These variables are all season dependent (Holland, 2001; Armstrong & Milne, 1995; Hopkins, 2000; McNaughton, 1979). Sward species abundance under a given set of environmental conditions is determined by the outcome of competitive interactions mediated by avoidance of, and tolerance to, grazing (Briske, 1996). Again these mechanisms are season dependent, with each species following its own phenological pattern of development (Bullock *et al*. 1994b; Bullock *et al*. 2001). The sward parameters selected were considered to give the most information on the value of the vegetation to herbivores (Eadie & Black, 1968), and are also those used by conservationists to give indications of biodiversity value (Dennis *et al*. 1995).

The point quadrat technique is one of various methods available for assessing sward structure and species abundance (Goodall, 1952, cited in Grant, 1993; Elzinga *et al*. 2001). It comprises one or more pins mounted on a frame either vertically or at an angle, which the recorder pushes through the sward (Grant, 1993). This technique has been commonly used to assess lowland sward responses to management (Bullock, 1996), and can be used to collect information on plant cover and sward structure, and to give estimates of biomass. The point quadrat method may be less susceptible to bias by the observer than other techniques for measuring species percent cover (Grant, 1993). However, it has been criticised for: the large number of pins required to achieve acceptable confidence intervals (Snedecor and Cochran, 1989); the length of time taken to collect data (Kent & Coker, 1992; Bullock, 1996); the low probability of recording rare species (Grant, 1993). Point quadrats are particularly useful for fine-scale studies of sward responses to management, since they give quantitative estimates of species cover, reputed to be likely to be biased by the observer than visually estimated quadrats (Grant, 1993). Inclined point quadrats are often used in measurements of canopy structure, with the height of each contact recorded (Bullock, 1996). However, they are generally assumed to be of greatest use on short grassland communities and on relatively level ground (Bullock, 1996). This study includes a comparison of the use of the single-pin inclined point quadrat and visual estimates of small quadrats for determining sward species abundance.

4.2 OBJECTIVES

Objective: Investigate the effect of sheep grazing regimes on upland plant communities.

Sub-objectives:

1. Measure the effect of three sheep grazing treatments (continued year-round grazing, change to off-wintering, change to zero grazing,) on sward structure and species abundance.
2. Assess the point quadrat method as a technique for describing change in sward structure (height and sward components) and species abundance.
3. Compare the variability of repeated trials (i.e. within-observer error) of visual quadrats and point quadrats.

4.3 METHODS

4.3.1 Sward sampling

The design of the monitoring scheme described here was determined by I.A.R. Hulbert in 1998. Data collection was carried out by J.P. Holland in 1998 and 1999, and by the author in 2000 and 2001.

A total of nine sampling sites on four plant communities were selected to give the maximum number of grazing treatment × community combinations (Table 4.1). As not every community occurred in every grazing system, a completely balanced design could not be used. Four 20-m permanent transects were set up at each sampling site. Within the sites, transects were positioned on representative areas of the community, at distances of 10 to 20 m from each other, and usually in a regular pattern, for example with the transects running in a line across the slope, to facilitate transect re-location. In patchy communities (CG11), transects were set up wherever sufficient areas of the vegetation type occurred. On each transect twenty single-pin inclined point quadrats were taken at exactly 1 m intervals.

Table 4.1. Grazing treatments, communities and dates sampled.

		Year			
Grazing System	**NVC Type**	**1998**	**1999**	**2000**	**2001**
Year-round grazed, (Auchtertyre Glen)	M17	25 Sept			6 Aug
	U5	16 July			7 Aug
	CG11	24 Sept			2 Aug
	U7	22, 31 July			31 Jul
Change to summer-only grazed, (Kirkton Glen sides)	U5		4 Aug	21, 24 Aug	26 Jul
	CG11	24 Aug	6 Aug	23 Aug	24 Jul
	U7	10 Aug	3 Aug	22 Aug	23 Jul
Change to zero grazing, (Kirkton Glen Woodland)	M17	11 Sept			30 Jul*
	U5	21, 30 Aug			24, 30 Jul^{+}

*only two transects re-located, two re-installed in similar positions; $^{+}$ all transects re-instated in slightly different position following mounding of woodland. Sampling carried out by John Holland in 1998 and 1999, and by Meg Pollock in 2000 and 2001.

The point quadrat used in this study (Fig 4.1, after Grant 1993) is a collapsible three-legged device with a rod guide mounted at 32.5° to horizontal (Grant, 1993). The rod, which has a pin mounted at the tip, was pushed through the guide, and every contact of the pin with the vegetation was noted. Multiple pin point quadrats are sometimes used to describe vegetation (Bullock, 1996), but here, a single set of point contacts was recorded for every point quadrat. The bar of the point quadrat was clamped into position at 60 cm on the vertical leg of the quadrat, such that when set up on level ground, the scale on the rod read ‘0’ when the tip of the pin was resting gently on the ground. On uneven ground, the measured height of the ground is subtracted from all the other contacts of the sward, to give actual height. In the ungrazed treatment in 2001, the U5 sward was occasionally higher than the point quadrat guide.

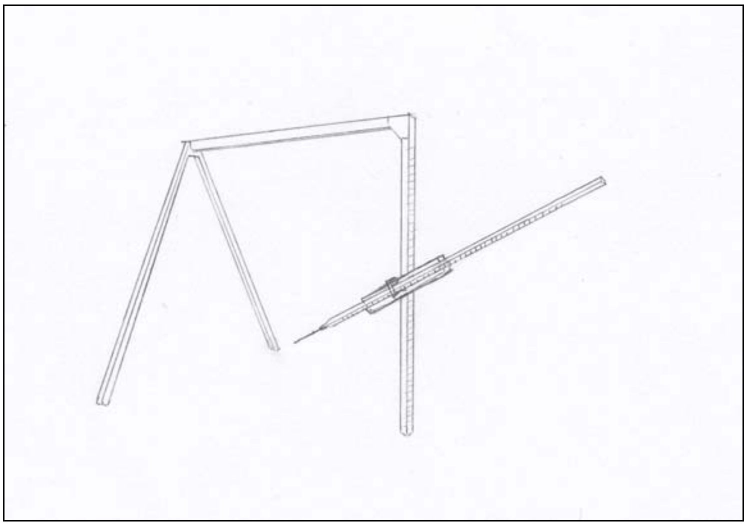

Fig 4.1. Inclined point quadrat, after Grant (1993).

To sample the fraction of the sward above 60 cm, the guide was moved to 90 cm on the vertical leg of the point quadrat, and the heights of the contacts adjusted accordingly. Two surveys were made of each transect of the ungrazed U5 community, once with the guide at 90 cm and once in the normal position. The data for this area therefore represents two sections through the sward, one above the other, with no overlap in height. This is unlike the normal method, which involves collecting information on a single line of points through the sward.

The variables height, type (species if live, dead standing or litter if dead), and leaf/stem/flower were recorded for each contact. Dead standing material was defined as dead material still attached to the plant; litter was defined as dead material that was no longer attached to the plant. Baseline data were collected in 1998 before the grazing systems were imposed, and repeated in 2001. The exception to this was the U5 community in the summer-only grazed treatment, for which baseline data were collected in 1999 as the precise route of the woodland fence was not known prior to this. The sites in the change to summer-only grazing treatment were also sampled in the intervening years, 1999 and 2000.

4.3.2 Comparison of visual and point quadrats

The variability of repeated measures of the same sample collected in relatively quick succession by the same observer gives a useful indication of the repeatability of a technique. In this sub-study, a comparison was made of the variability of repeated measures of two techniques: visual estimates of 20 × 20 cm quadrats; single-pin inclined point quadrats. The small size of the visual quadrat was selected as it allows a confident estimation to be made in swards that are a fine-grained mosaic of several species; a task that would be very difficult if normal 1 m × 1 m quadrats were used.

The field study was carried out over two hours on 21/4/03, in weather conditions that were moderately bad (raining, cool), giving a realistic simulation of observer mistakes generated through fatigue on a longer day in the field in better weather.

A metre tape was fixed to the ground. Three point quadrat samples were taken at precise 1 m intervals along the tape using the methods described in section 4.3.1. A total of 10 repeats of each point quadrat sample were made, moving the point quadrat between each repeat. The time taken to collect the data was noted.

Visual quadrat estimates were made of the same three points by laying the 20 × 20 cm quadrat with one side along the metre tape and the bottom right corner of the quadrat on the metre interval mark. Visual estimates were made by examining the quadrat and noting the percentage cover of each species present, to the nearest 5 %. Where the species appeared to have less than 5 % cover, the value 1 % was assigned. Total percentage cover added up to more than 100 %. Ten repeats of each of the three samples were made using the visual quadrats, moving the quadrat each time. A crib sheet was not used, since this would have allowed the observer to see the estimated percentages from the previous repeat. Again, the time taken to collect the data was noted.

The visual and point quadrats did not sample exactly the same locations, meaning that the data can only be used to compare the between repeat variability of the different techniques, not the mean species abundance.

4.3.3 Data analysis

Height analysis

Sward height data were compiled by taking the height of the first contact in every quadrat. Ideally, sward heights would have been collected at the same time every year. However, there were considerable differences in the date of sampling between years (Table 4.1). As sward height changes through the growing season, it was necessary to test whether the effect of treatment on height was greater than the effect of date of sampling. A GLM model was used for community by community analyses, with height as the response variable, fitting the model t + year × treatment, where t is the number of days since July 1^{st}, and year and treatment are factors. Non-significant terms were dropped progressively to achieve a minimal model.

Power to detect changes in height

In a statistical context, power is the probability that an actual difference between two samples will be detected (i.e. the probability that a false null hypothesis will be correctly rejected) (Zar, 1999). It can be used to determine the minimum detectable difference between two means for a given sample size, or conversely to determine the minimum number of samples required to detect a given difference between the means of two samples.

The difference in means that can be detected statistically depends on five factors: the type of statistical test used, the power of the test, the significance level required, the sample size and the estimation of variance (Nagy *et al*. 2002). Here, calculations are made for a one sample t-test (as the quadrats were paired) with power 0.9, a significance level of 0.05, using the pooled variance measured in the field.

A power analysis was performed to determine the minimum change in mean sward height that could be detected with a sample size of 80 permanent quadrats. On the advice of I. Nevison, BioSS Statistician, the difference in height over time for each permanent quadrat in the U5 community was calculated, and the variance was entered into Equation 4.1:

$$\delta = \sqrt{\frac{s^2}{n}} \cdot (t_{\alpha,\nu} + t_{\beta(1),\nu})$$

Eqn .4.1.

where δ = minimum detectable difference between two means, n = number of samples, s^2 = sample variance, $t_{\alpha,\nu}$ = t-statistic for probability of Type I error (α, normally 0.05) with ν degrees of freedom, and $t_{\beta(1),\nu}$ = t-statistic for probability avoiding a Type II error (1-β, normally 0.9) with ν degrees of freedom.

Rearranged, the same equation gives the number of samples required to detect a given minimum difference between means (Zar, 1999):

$$n = \frac{s^2}{\delta^2} \cdot (t_{\alpha,\nu} + t_{\beta(1),\nu})^2$$

Eqn. 4.2.

Vertical distribution of sward components

During analysis several months after the final data was collected, it became apparent that there had been considerable difference between observers in the method used to classify dead material. J. Holland, sampling in 1998 and 1999, classified only material where all tissue was dead but still attached to the plant as 'dead standing'. This meant that only material that grew in the previous growing season was classed as dead standing in 1998 and 1999. The author, sampling in 2000 and 2001, classified any hit to material where the majority of the tissue was dead as 'dead standing'. Any actual differences in the amount of dead standing material were therefore impossible to distinguish from observer differences. The vertical distribution of sward components was therefore presented with only hits to litter, bryophytes and vascular plant material separated.

Species abundance

For clarity, each community was analysed separately. The percentage of sward (Grant, 1993) is the total numbers of hits to live plant material of each species. The percentage of sward was calculated for each transect at each sampling time, as there were insufficient hits per quadrat to perform analyses at the quadrat level. The data were not normally distributed and were therefore transformed by taking the square root. The start and end points of the monitoring regime for each treatment × transect combination were analysed using Principal Components Analysis (PCA) in MINITAB, with all species included as variables in a correlation matrix. As rare species did not appear to influence the first axis, down-weighting of rare species was not carried out.

Power to detect change in species abundance, visual quadrats and point quadrats

The point quadrat data were summarised by calculating the percentage abundance of each species in each trial and each quadrat. The variance and mean of the 10 trials of the visual quadrats and the point quadrats were calculated.

Since repeated trials of a few transects are likely to under-estimate the within observer error, the power equation for unpaired samples (Eqn. 4.3) was used to estimate sample sizes required using either point quadrats or visual quadrats (I. Nevison, pers. com.)

$$n \geq \frac{2s_p^2}{\delta^2} \cdot \left(t_{\alpha,\nu} + t_{\beta(1),\nu}\right)^2$$

Eqn. 4.3

where δ = minimum detectable difference between two means, n = number of samples, s_p^2 = pooled sample variance, $t_{\alpha,\nu}$ = t-statistic for probability of Type I error (α, normally 0.05) with ν degrees of freedom, and $t_{\beta(1),\nu}$ = t-statistic for probability avoiding a Type II error (1-β, normally 0.9) with ν degrees of freedom (Zar, 1999).

The minimum change in species percentage of sward that could be detected was calculated using Equation 4.3, using the variance of the most variable species in the repeated quadrat trial and power = 0.9, for both the point quadrats and visual estimates.

4.3.4 Note on experimental design

The results presented are generated from a systems scale study which gave an opportunity to examine the effects of changes in grazing treatment on sward characteristics. Grazing system and location are confounded, with 1) the year-round grazing (control) treatment only in Auchtertyre Glen, 2) the change from year-round to summer only grazing treatment only in the upper part of Kirkton Glen, and 3) the change from year-round to 'zero' grazing treatment only in the lower part of Kirkton Glen. In a systems scale study of this size, it is not possible to replicate treatments. The focus is therefore on any sward changes over time within each grazing system × community combination, not the differences in baseline sward characteristics between the locations.

4.4. RESULTS

4.4.1 Changes in sward height

The U5 community was the only community that showed a significantly different change in sward height between treatments (i.e. an interaction between year and treatment) ($F_{1,554}$=6.40, Table 4.2). Inside the woodland, the average height of the U5 community increased over the four year period, while the control and off-wintering treatments did not change significantly. The effect of date of sampling was often confounded with year, but is only considered likely to be an explanation for change in height for the year-round grazed CG11 community, as this was sampled late in 1998 and early in 2001.

Table 4.2. Mean sward heights in cm, (± s.e). n = 80 per year × grazing treatment combination. * P <0.05, significant interaction between year and treatment.

Grazing Treatment	Community	Year 1998	1999	2000+	2001
Year-round grazed	M17	15.1 (0.8)			14.0 (0.9)
	U5	12.9 (0.6)			13.1 (0.8)
	CG11	7.5 (0.5)			9.6 (0.7)
	U7	11.5 (0.5)			13.4 (0.7)
Off-wintered	U5		15.1 (0.6)	10.6 (0.7)	17.5 (0.8)
	CG11	9.1 (0.5)	8.0 (0.6)	5.5 (0.5)	9.7 (0.7)
	U7	10.8 (0.6)	12.5 (0.8)	7.9 (0.5)	14.3 (1.1)
Ungrazed	M17	14.9 (0.8)			16.7 (0.9)
	U5	18.5 (0.9)			*23.0 (1.3)

+An outbreak of antler moth in Kirkton Glen in 2000 may have resulted in reduced sward heights (J. Holland, pers. com.).

Variance of differences in height in U5 community

The variance of the difference in height of permanent point quadrats was considerable (Table 4.3). A power analysis (Eqn. 4.1) based on the variances in Table 4.3 and with power equal to 0.9 shows that it would be possible to detect a change in height of 2.9 cm in Auchtertyre Glen and 4.8 cm in Kirkton Glen.

Table 4.3. Pooled mean and variance of difference in height and minimum detectable difference of U5 permanent point quadrats. The minimum detectable difference is for power 0.9 and n = 80.

Treatment & location	Pooled Mean height in cm (1998 + 2001)	Variance of height differences (1998-2001)	Minimum detectable difference (cm)
Year round grazing, Auchtertyre Glen	12.9	60.4	2.9
Off-wintering, Kirkton Glen	18.5	167.8	4.8

4.4.2 Changes in total amount and vertical distribution of sward components

The total number of point quadrat hits in each sampling area was fairly constant (Table 4.4). The large increases in dead standing material and the apparent reduction of leaf, stem and flower material are likely to be related to observer differences rather than actual changes, but unfortunately it is not possible to distinguish the two.

The vertical distribution of sward components is presented for the U5 community (Fig 4.2), since this was the only community to occur in all three treatments. Following three seasons without grazing, the sward profile changed, with fewer hits at the base of the sward and a greater height overall. In both the off-wintered and year-round grazed treatments, the sward density at the base increased. The profile of the year-round grazed treatment became more concave.

Table 4.4. Numbers of hits to sward components, expressed as hits per 100 pins.

Treat.	Comm.	Year	Leaf	Dead St.	Bryo.	Litter	Flower	Stem	Bare Ground	Total no. hits per 100 pins
Year Round Grazed	M17	1998	308	49	66	79	9	93	0	603
	M17	2001	278	134	56	70	4	74	0	615
	U5	1998	458	24	84	64	16	50	0	695
	U5	2001	439	156	133	98	6	19	0	850
	CG11	1998	336	26	75	68	8	21	0	534
	CG11	2001	341	83	106	89	6	23	1	649
	U7	1998	383	31	115	68	4	24	0	624
	U7	2001	434	123	134	95	10	45	0	840
Off Wintered	U5	1999	621	16	109	86	28	56	0	916
	U5	2000	350	120	83	84	3	38	0	676
	U5	2001	441	120	81	91	19	36	0	789
	CG11	1998	380	14	90	61	16	56	0	618
	CG11	1999	324	20	86	119	10	44	0	603
	CG11	2000	225	69	100	75	3	41	1	514
	CG11	2001	319	65	90	79	10	44	0	606
	U7	1998	343	15	124	71	16	41	0	610
	U7	1999	500	8	118	88	10	59	0	781
	U7	2000	421	89	100	103	3	65	0	780
	U7	2001	429	24	126	104	18	60	1	761
Un-Grazed	M17	1998	319	29	45	70	6	89	0	558
	M17	2001	270	126	54	56	3	80	0	589
	U5	1998	505	33	53	76	16	79	0	761
	U5	2001	390	200	58	85	15	23	0	770

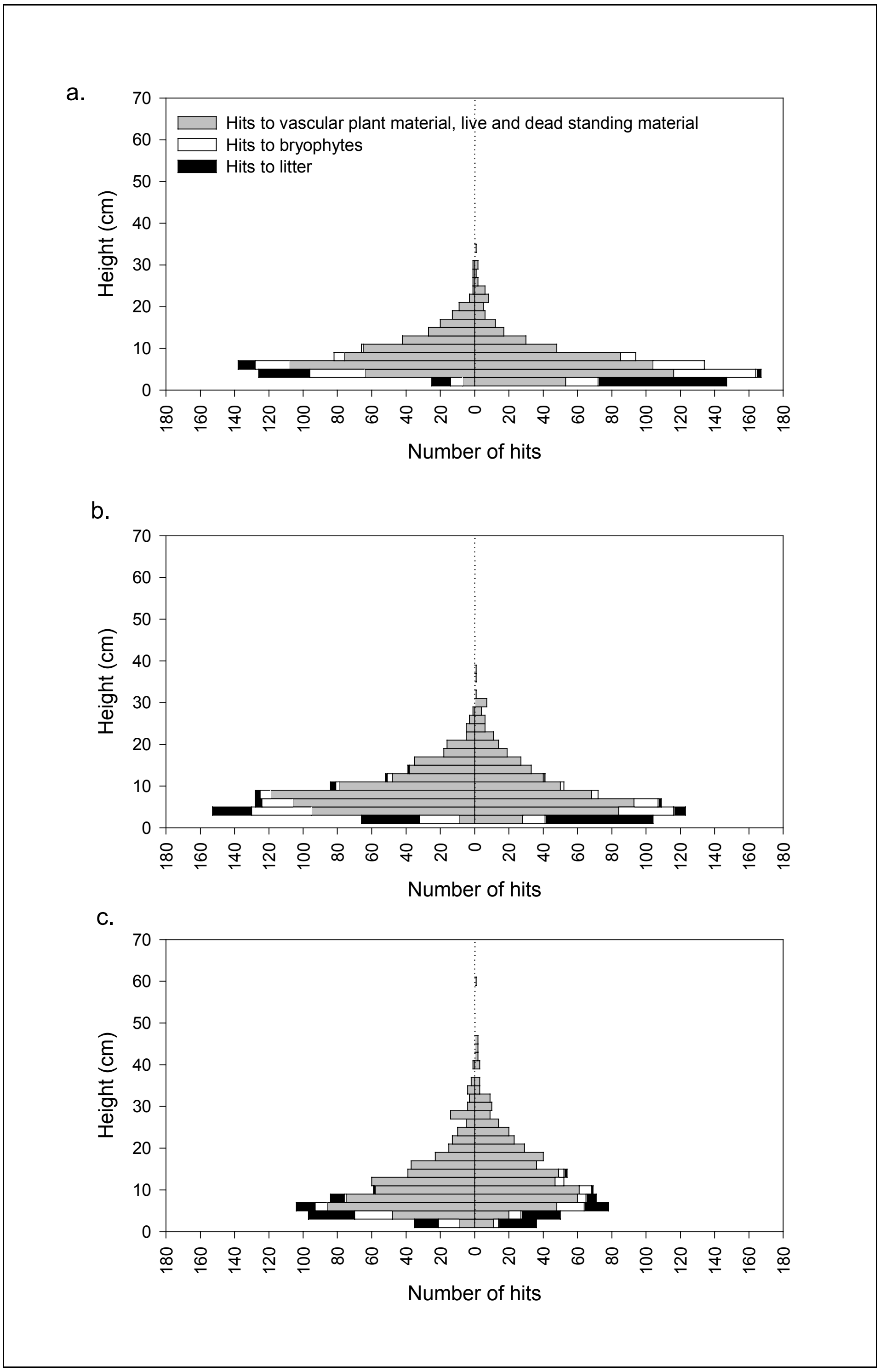

Fig 4.2. Vertical distribution of sward structure in U5 community: left = baseline measurement (1998 or 1999), right = measurement in 2001. Treatments: a – continued year-round grazed; b – change to off-wintered; c – change to ungrazed.

4.4.3 Changes in species abundance

The PCA diagram for the community included in all three treatments shows that there were initial differences in species abundance between treatments (starting points of arrows), and that all of the transects moved in a similar direction (Fig 4.3). PCA axis 1 represents mainly differences between sites, with plants that grow better in damp acidic situations on the left and those that grow better in dry basic conditions on the right (Table 4.5). PCA axis 2 represents mainly differences over time, with decreases in *Nardus stricta* and *Juncus effusus* and increases in *Viola riviniana* and *Deschampsia flexuosa* (Table 4.5).

Table 4.5. PCA loadings of U5 species in all treatments.

Species	PCA 1	PCA 2	Species	PCA 1	PCA 2
Narthecium ossifragum	-0.221	0.086	*Carex hostiana*	0.059	-0.031
Trichophorum cespitosum	-0.202	0.086	*Viola palustris*	0.065	0.198
Potentilla erecta	-0.194	0.005	*Festuca ovina*	0.07	0.056
Molinia caerulea	-0.193	0.064	*Luzula multiflora*	0.085	0.237
Vaccinium myrtillus	-0.191	-0.03	*Lysimachia nemorum*	0.089	0.162
Deschampsia flexuosa	-0.128	-0.232	*Juncus effusus*	0.092	0.031
Pedicularis sylvatica	-0.123	0.013	*Cynosurus cristatus*	0.099	-0.072
Erica tetralix	-0.113	0.044	*Euphrasia* sp.	0.109	0.16
Lichens	-0.075	0.024	*Carex panicea*	0.116	-0.165
Carex pilulifera	-0.071	0.197	*Persicaria vivipara*	0.118	-0.116
Danthonia decumbens	-0.062	0.096	*Bellis perennis*	0.133	-0.039
Holcus mollis	-0.034	-0.141	*Lotus corniculatus*	0.133	-0.039
Juncus acutiflorus	-0.034	-0.141	*Prunella vulgaris*	0.134	0.216
Alchemilla glabra	-0.024	-0.15	*Carex palescens*	0.135	-0.053
Galium saxatile	-0.014	0.026	*Viola riviniana*	0.143	-0.249
Carex bigelowii	-0.014	0.126	*Carex pulicaris*	0.149	0.003
Juncus squarrosus	-0.014	0.292	*Trifolium repens*	0.153	0.122
Poa sp.	-0.009	0.096	*Holcus lanatus*	0.158	0.208
Anemone nemorosa	-0.008	-0.221	*Helictotrichon pratense*	0.175	0.087
Carex nigra	-0.007	-0.087	*Cerastium fontanum*	0.183	-0.122
Carex binervis	0.003	-0.156	*Deschampsia cespitosa*	0.184	-0.177
Hieracium sp.	0.014	-0.074	*Thymus polytrichus*	0.2	-0.153
Ranunculus repens	0.017	0.068	*Plantago lanceolata*	0.204	-0.009
Equisetum sp.	0.019	0.029	*Agrostis* sp.	0.215	0.02
Nardus stricta	0.022	0.294	*Anthoxanthum odoratum*	0.247	0.196
Bryophytes	0.044	-0.003	*Festuca rubra*	0.277	-0.018
Carex demissa	0.058	-0.132	*Ranunculus acris*	0.292	0.076

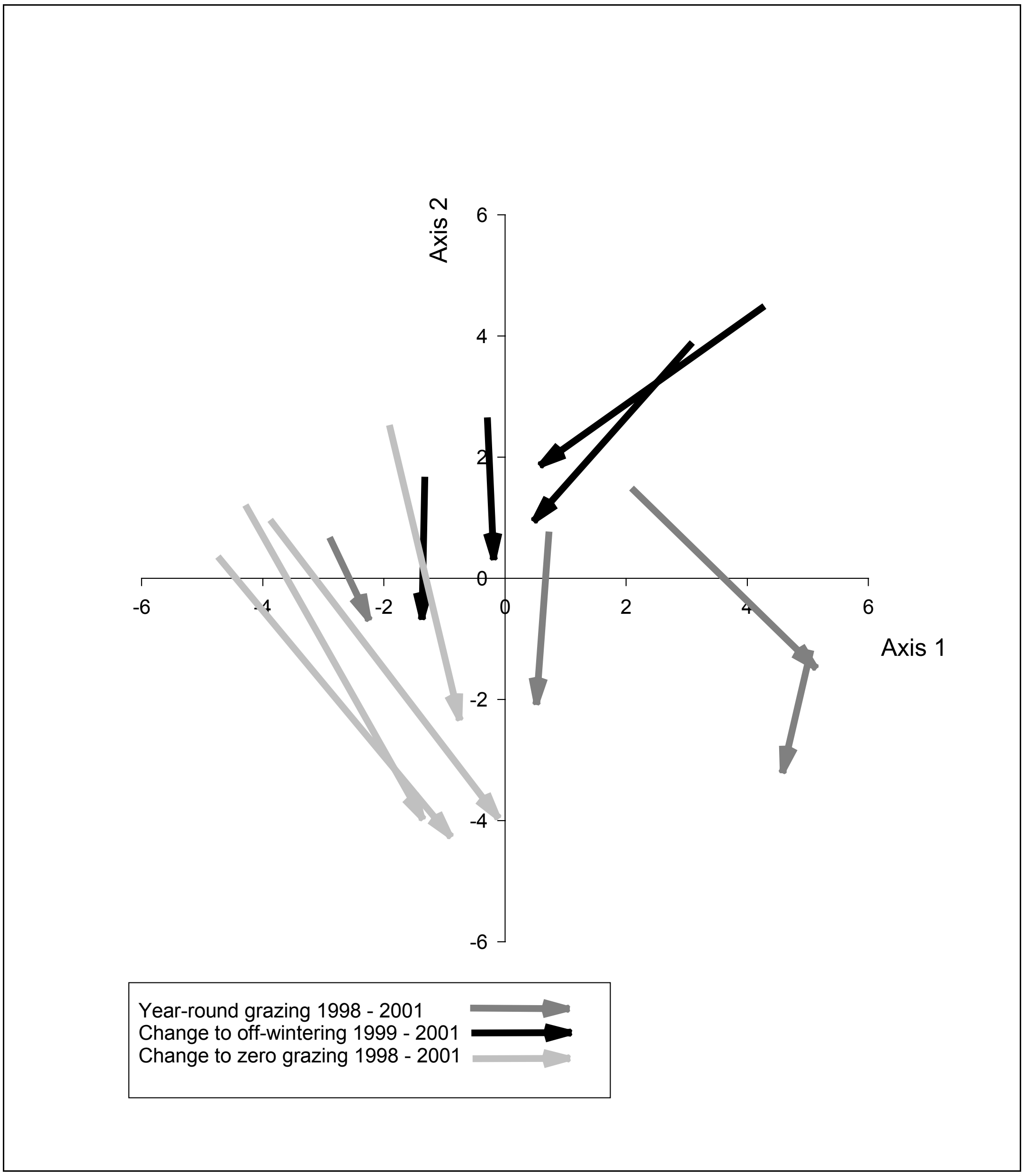

Fig 4.3. Trajectories of transects in U5 communities of species abundance as live percentage of sward under different treatments. Axis 1 explains 15 % of the variation, axis 2 explains 10 %.

4.4.4 Comparison of visual and point quadrats

The variability of repeated trials of visual quadrats was considerably less than the variability of repeated trials of point quadrats (Table 4.6; Table 4.7). The time taken to collect one point quadrat sample was 2 minutes, while visual quadrats took 5 minutes each.

Table 4.6. Mean and variance of percentage of each species in three quadrats measured using repeated trials of the point quadrat.

		Trial											
Quadrat	Species	1	2	3	4	5	6	7	8	9	10	Mean	Var.
1	*Agrostis* sp.	0	14	17	0	0	0	0	0	0	0	3.1	42.9
	Bryophytes	25	14	42	50	60	43	60	0	33	0	32.7	501.2
	Carex binervis	0	29	0	0	0	0	0	0	0	0	2.9	81.6
	Dead standing	0	0	0	0	20	0	0	0	0	0	2.0	40.0
	Festuca ovina	13	0	0	0	20	0	0	0	33	0	6.6	137.1
	Galium saxatile	0	0	0	0	0	0	0	0	0	20	2.0	40.0
	Litter	13	0	0	17	0	0	0	25	0	20	7.4	101.0
	Nardus stricta	50	29	33	33	0	57	40	75	33	60	41.1	430.1
	Potentilla erecta	0	14	8	0	0	0	0	0	0	0	2.3	24.7
2	Bryophytes	25	33	50	50	0	50	100	33	0	25	36.7	836.4
	Carex binervis	50	0	0	0	0	0	0	0	0	0	5.0	250.0
	Dead standing	0	0	0	0	25	0	0	0	0	0	2.5	62.5
	Litter	0	33	0	17	0	50	0	33	0	25	15.8	346.5
	Nardus stricta	25	33	50	33	75	0	0	33	67	50	36.7	620.4
	Potentilla erecta	0	0	0	0	0	0	0	0	33	0	3.3	111.1
3	*Agrostis* sp.	0	0	0	0	0	0	0	33	0	0	3.3	111.1
	Bryophytes	50	33	33	25	43	0	0	33	40	0	25.8	360.7
	Dead standing	25	0	0	25	0	0	0	0	0	0	5.0	111.1
	Festuca ovina	0	0	33	25	0	0	0	0	0	0	5.8	155.1
	Galium saxatile	0	0	0	0	14	0	0	0	0	0	1.4	20.4
	Litter	0	17	0	0	0	0	0	33	0	20	7.0	144.3
	Nardus stricta	25	50	33	25	43	75	67	0	60	80	45.8	644.9
	Potentilla erecta	0	0	0	0	0	25	33	0	0	0	5.8	155.1

Table 4.7. Mean and variance of percentage of each species in three quadrats measured using repeated trials of the visual quadrat.

		Trial											
Quadrat	Species	1	2	3	4	5	6	7	8	9	10	Mean	Var.
1	*Agrostis* sp.	1	5	1	1	1	1	1	5	1	5	2.2	3.4
	Brypophytes	90	95	95	90	95	90	95	95	95	90	93.0	6.0
	Carex binervis	5	5	5	0	5	0	5	5	0	1	3.1	5.5
	Dung	5	5	5	5	10	10	5	5	10	10	7.0	6.0
	Festuca ovina	0	0	0	1	1	1	5	1	1	5	1.5	3.3
	Galium saxatile	5	5	1	1	5	1	5	1	1	5	3.0	4.0
	Nardus stricta	30	35	35	30	35	25	25	35	35	30	31.5	15.3
	Potentilla erecta	5	5	1	5	5	5	5	5	5	1	4.2	2.6
2	*Agrostis* sp.	1	1	0	1	1	1	1	1	1	1	0.9	0.1
	Brypophytes	70	70	75	75	75	75	75	80	75	75	74.5	7.3
	Carex binervis	5	5	5	1	1	0	1	0	0	1	1.9	4.3
	Dung	0	0	0	0	0	0	0	0	0	0	0.0	0.0
	Festuca ovina	1	5	5	1	1	1	1	1	1	1	1.8	2.6
	Galium saxatile	5	5	1	1	0	5	5	1	5	1	2.9	4.5
	Luzula multiflora	5	5	5	5	5	5	5	5	5	5	5.0	0.0
	Nardus stricta	60	50	45	50	45	35	45	35	40	35	44.0	59.0
	Potentilla erecta	1	0	1	5	0	1	1	0	1	0	1.0	2.0
3	*Agrostis* sp.	5	0	5	5	1	5	1	5	5	5	3.7	4.0
	Brypophytes	75	75	95	95	95	95	95	95	95	95	91.0	64.0
	Carex binervis	0	1	0	0	0	0	0	0	1	0	0.2	0.2
	Dung	20	20	15	15	10	20	15	15	5	15	15.0	20.0
	Festuca ovina	5	5	5	5	1	5	1	5	1	1	3.4	3.8
	Galium saxatile	1	5	5	1	1	5	5	5	5	1	3.4	3.8
	Luzula multiflora	15	20	15	15	15	15	20	15	15	15	16.0	4.0
	Nardus stricta	10	10	10	10	10	10	10	15	10	10	10.5	2.3
	Potentilla erecta	5	5	1	1	5	5	5	1	1	5	3.4	3.8

The level of variance in repeated-trial assessments of percentage cover is related to the abundance of the species of interest. Species with either low or high abundance tend to have low variance, while those with medium abundance have high variance (Fig 4.4).

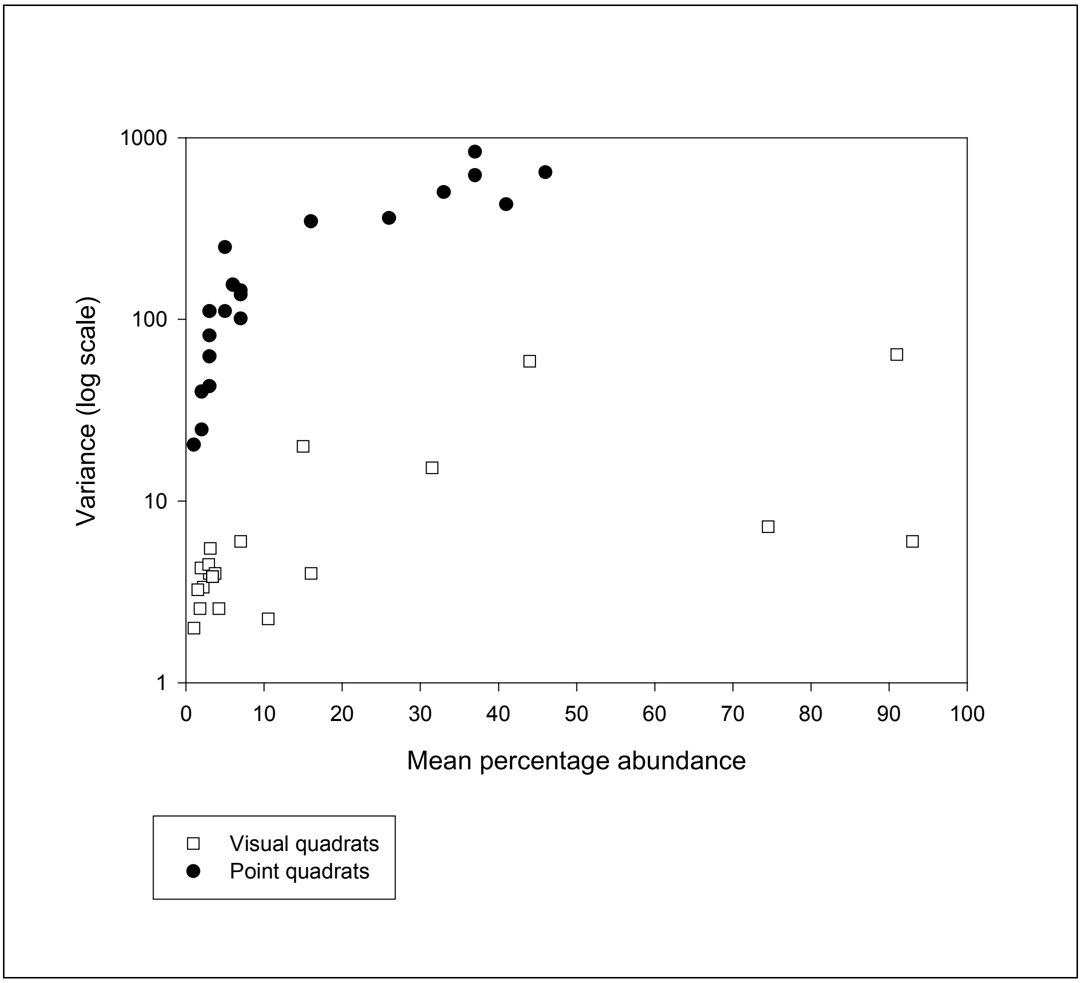

Fig 4.4. The relationship between mean and variance of assessments of percentage cover made with repeated trials using either point quadrats or visual quadrats. Points are the mean versus the variance of 10 measures of species abundance from Tables 4.6 and 4.7. Note that the y-axis is logarithmic, due to the much greater variability between trials using point quadrats than betweens trials using visual quadrats.

Power analysis of species abundance

The sample sizes required to detect an absolute change in abundance of a common species of 10 % were calculated using Eqn. 4.3 for both point quadrats and visual estimates, for power 0.9 and at a significance level of 0.05. The results (Table 4.8) indicate that many fewer quadrats are required if visual estimates are made rather than using point quadrats. Even when the greater time required to survey visual quadrats is taken into account, it is still more economic to survey visual quadrats.

Table 4.8. Sample sizes required to detect an absolute change of 10 % in a common species using either point quadrats or visual estimates, and estimate of time taken to collect such data.

Method	Largest mean and variance for *Nardus* from Tables 4.6 and 4.7				
	Mean	Variance	n required	Time for n = 1	Time for n required
Point quadrat	45.8	644.9	140	2 mins	4 hours 40
Visual quadrat	44.0	59.0	15	5 mins	1 hour 15

4.5 DISCUSSION

4.5.1 Treatment effects on sward height

In this study, an increase in sward height occurred in the treatment where grazing was removed, but significant interactions with time were not observed in the other treatments. The changes in sward height were smallest in the system where the grazing pattern was unchanged. However, intermediate measurements (i.e. in 1999 and 2000) were not made in this system, so fluctuations in the height of the year-round grazed swards may have occurred.

Sward responses to environmental conditions can be slow, and vegetation can take long periods of time to re-adjust to historical changes (Hill *et al.* 1992). Semi-natural swards are not static entities, even if they are managed under a consistent regime for long periods of time (Rawes, 1981). Abiotic factors, such as inter-annual variability in weather patterns can affect plant community structure (Donlan *et al*. 2002) and sward productivity (O'Connor & Roux, 1995; Grant & Hunter, 1968). In the treatment where year-round grazing was maintained there may therefore have been fluctuations in sward characteristics in the years between measurements. In the ungrazed treatment, the expected result was found: an increase in sward height. Increases in sward height following the removal of sheep grazing have been noted by numerous authors (Hope *et al*. 1996; Miller *et al*. 1999; Baines *et al*. 1994; Rawes, 1983; Cadenasso *et al*. 2002).

Assessment of point quadrat method: monitoring sward height

The number of samples taken was sufficient to detect a change in mean sward height ranging from 2.9 to 4.8 cm, depending on the magnitude of the mean (where the mean is large, variability in height measurements is greater and it is more difficult to detect changes). A sample size sufficient to detect changes of 2.5 cm is recommended, since this is a change likely to be of biological significance. In Kirkton Glen this would require a sample size of 284 permanent point quadrats per community.

The statistical test used to assess whether there had been any interaction between sward height and treatment was performed on the pooled data of all samples from each community, allowing a significant difference in height to be detected although the minimum detectable difference using a t-test would not have been significant.

The point quadrat method is a time-consuming method of collecting information on sward height. It would therefore have been better to measure sward height using, for instance, the HFRO sward stick (Barthram, 1986), which would have allowed a larger number of samples to be collected in a shorter period of time. Additionally, since the sliding plate of the HFRO sward stick has a larger area than the tip of the point quadrat, the variability in data is likely to be lower if the HFRO sward stick is used. However, the point quadrat does provide information about sward structure. If changes in sward structure are the dependent variable of interest, the point quadrat should be used.

4.5.2 Treatment effects on amount and vertical distribution of sward components

It is unfortunate that differences occurred between observers in the classification of dead material. Amounts of live and dead material were assessed in a separate study of sward production (Pollock *et al*. 2003). Little change was observed in the weight of dead standing material in harvested cuts taken in 1998 and 2001 in the two grazed treatments, suggesting that the differences recorded in the present study could be attributed to observer differences only.

4.5.3 Treatment effects on species abundance

The PCA diagram of transect trajectories in the U5 community suggest that changes in species relative abundance have occurred. However, the apparent decreases in two of the common species, *Nardus stricta* and *Juncus effusus*, probably relate to observer error not to actual changes, since both of these species often have dead material at the tips of their leaves, a major source of difference in recording.

In the short and medium term, changes in sward structure occur in response to grazing management, whilst in the longer term, species abundance, and eventually species composition, respond (Miles, 1988). After only two to three years of treatments, little change in species abundance would be expected, as upland grassland swards tend to be very stable (Welch & Scott, 1995). For example, a detailed survey of upland calcareous grassland in Kirkton Glen was carried out in 1985, and repeated in 1999 (MacDonald, 1985; Holland, unpublished data), and showed very few changes in species occurrence in 10 cm × 10 cm cells. Remarkably constant species composition has been found in North American grasslands where herbivores have been excluded for three (Hickman & Hartnett, 2002; Fahnestock & Detling, 2002) and even 30 (Coughenour, 1991) years. Long-term studies of botanical composition are required as changes happen slowly (Jones *et al*. 1995). The objectives for monitoring should be carefully defined to ensure the changes of interest can be detected.

4.5.4 Comparison of visual and point quadrats

Point quadrats were originally conceived as a method for measuring species abundance in this study as they are reputedly less subjective than visual estimates of cover (J. Holland, pers. com.). The between-trial error of point quadrats was much greater than that of visual estimates. As point quadrat data are time-consuming to collect for the quality of data generated (Legg, 2000; Kent & Coker, 1992; Bullock, 1996) and are rather difficult to use on steep slopes, their use would not be recommended for further studies. The swards in Kirkton and Auchtertyre Glen are often very fine grained, making a visual estimate of cover in a standard 1 m × 1 m quadrat (Kent & Coker, 1992) effectively impossible. For this reason small quadrats (20 cm × 20 cm), which are larger than the majority of *Nardus* tussocks at the site but should be small enough to allow a reliable estimate of percentage cover, are proposed in the following section (4.5.6). A large number of small permanent quadrats would give better data for less time in the field than the point quadrat method used in this study.

4.5.5 Comment on experimental design

If all of the communities studied had occurred within each treatment applied, the experiment would have been balanced, simplifying data analysis and giving more wide-ranging results. However, in order to generate results applicable to real farming systems, the HSNW project is managed at a systems scale, and the constraints conferred by this must be accepted. However, in addition to the absence of communities from some treatments, only one site per treatment was selected to represent a community. While introducing further sites to represent communities would be still an example of pseudo-replication, it would be desirable to determine whether the changes observed are occurring in a given community across the site as a whole. Given the concerns of the author on the experimental design, and on the point quadrat method for determining species abundance, (which were inherited from the start of the study) a proposal is presented below which outlines methods the author considers to be adequate to address the aims and objectives of the grazing study. These are to identify the impact of the grazing treatments in the HSNW project on the sward characteristics of greatest interest, namely changes in sward height, amount of dead standing material at the top of the sward and dominant species abundance.

4.5.6 Sward Monitoring Proposal

The objectives of the sward monitoring proposed are to:

i) quantify the changes in mean sward height, to detect a change of ± 1.5 cm;
ii) quantify the change in percentage top cover of dead standing material, detecting a minimum change in abundance of 10 %;
iii) quantify changes in percentage top cover that occur in dominant species (defined as greater than 10 % cover), detecting a minimum absolute change in abundance of 10 % .

The above objectives are to detect a change at a threshold of significance of 0.05 with a power of 0.9.

The plant communities of interest are M17, U5, CG11 and U7. These have been selected as they occupy large areas in both Kirkton and Auchtertyre Glens, and have animal production or conservation significance.

Methods

Sampling areas

Vegetation in two valleys, Kirkton Glen and Auchtertyre Glen, will be studied. One treatment is applied in Auchtertyre Glen (continued year-round grazing), and two in Kirkton Glen (change to off-wintering and change to zero grazing). The four plant communities of interest do not occur throughout the treatments. Where one of the communities occurs in a treatment, three spatially separate sampling areas, representative of the community as a whole, will be selected. All four communities occur in the year-round grazed treatment. Three communities occur in the off-wintered treatment, and two in the ungrazed treatment. There will therefore be a total of 27 sampling areas (4 communities × 3 areas) + (3 communities × 3 areas) + (2 communities × 3 areas).

Each sampling area will be 30 m × 30 m. The north-east and south-west corners will be marked with a metal rod, buried with the tip just above ground level, and its position recorded using GPS. A post taller than the surrounding vegetation will be set up 5 m north of the metal rod. During sampling, the area will be marked by inserting canes at the corners of the 30 m square, with the four sides of the sampling area running parallel to north, south, east and west.

Sward height and percentage of dead standing material

Sward heights will be assessed using the HFRO sward stick (Barthram, 1986) or a similar home made device for swards over 30 cm. Using the variation in Table 4.3 and Equation 4.2, it has been calculated that 284 measurements would be sufficient to determine a change in mean height of 2.5 cm with power 0.9. Sward height will be measured over the entire area by walking in a systematic pattern and taking a sward height measurement after every double pace. The square will be walked by starting from the NE corner and going west (giving approximately 10 measurements). When the far side of the square is reached, a pace south will be taken, followed by a walk east back to the other side of the square. This pattern will be repeated until 284 measurements have been obtained. At each measurement, a note will be made of whether the material hit is live or dead (the actual part touched, rather than the rest of the attached plant material). A dictaphone will be used to speed up the measurement process. The area of the tool that makes contact with the vegetation on the HFRO sward stick is much greater than the area of the pin that makes contact when using a point quadrat. The variability of data collected using the HFRO sward stick may therefore be considerably less than that collected using the point quadrat, meaning that a smaller number of samples might be required. 1000 sward stick measurements can be collected in one day (J. Holland, pers. com.).

The work will be carried out in July each year. Estimate of time required for survey of 27 sampling areas: 16 days per year.

Species abundance

Fifteen 20 cm × 20 cm permanent quadrats would be necessary to determine a 10 % change in absolute abundance of *Nardus stricta* (Table 4.8). Within the sampling square, three permanent transects will be set up, running across the slope at regular positions, with the ends marked using metal rods buried just below the surface of the ground. Five permanent quadrats will be located at recorded random intervals along the transects (Elzinga *et al*. 2001). Species percentage cover will be estimated visually to 5 % in each quadrat. Presence of species with less than 5 % cover will be noted. Where bare ground is present, its percentage cover will be noted. Since changes in cover can occur over the course of a growing season (Elzinga *et al*. 2001), three observers will be required to carry out the survey in a short space of time; all observers will be trained in order to minimise error in estimates of cover (Leps & Hadicova, 1992). At 5 minutes per quadrat, it would take 34 hours (approximately 6 days) to survey all the sampling areas.

Data analysis

Each community will be analysed separately. GLM will be used to analyse treatment effects on explanatory variables height and percentage of dead material. Species abundance change will be assessed qualitatively using PCA.

Timing of monitoring

Measurements of sward height and percentage cover of dead standing material will be carried out in all sampling areas in July of years 2003 – 2006. Species composition will be surveyed in 2003, 2004 and 2006. Information is required in 2003 to give a baseline against which to compare changes in 2004, to give an idea of the inter-annual variability in species cover. A change in management is planned for 2007 (re-introduction of sheep to the woodland) and monitoring will therefore be carried out in 2006 so that the management impact of this can be determined.

Comparison is made of the costs (expressed as person days) of the proposed monitoring scheme (Table 4.9) with the cost of the actual monitoring scheme carried out (Table 4.10) and the cost of a monitoring scheme designed to generate the same quality of data using point quadrats (Table 4.11). The cost of the actual method used was fairly low, but so was the quality of the data. For a study that will achieve power of 0.9 to detect a change in common species of 10 %, the point quadrat method is more expensive than the method based on visual estimates of quadrats.

Table 4.9. Estimated costs of proposed monitoring scheme, expressed as person days.

	Year				
Task	2003	2004	2005	2006	Total
Setting up sampling areas	9				
HFRO stick (284 per area)	16	16	16	16	
Visual quadrats (15 per area)	6			6	
Data entry	3			3	
Data analysis	5			5	
Presenting results				10	
Total	39	16	16	40	111

Table 4.10. Actual costs of monitoring carried out, expressed as person days. One day of fieldwork (8 hours) involves 2 hours walking in and out of the site and a total of 1 hour of break.

	Year				
	1998	1999	2000	2001	Total
Setting up sampling areas	3	1			
Point quadrats (80 per area)	9	3	3	9	
Data entry				4	
Data analysis				7	
Presenting results				5	
Total	12	4	3	25	44

Note: times for analysis and presentation are given for report to funding bodies, not for thesis.

Table 4.11. Estimated costs of point quadrat monitoring regime designed to achieve same level of power as proposed scheme using visual estimates of quadrats.

	Year				
	2003	2004	2005	2006	Total
Setting up sampling areas	9				
Point quadrats (284 per area)	265			265	
Data entry	3			3	
Data analysis	5			5	
Presenting results				5	
Total	282			278	558

The proposed monitoring scheme (Table 4.9) has several positive aspects. It should generate good quality data for less person days than using the point quadrat method (Table 4.11). As the visual quadrats are independent, there is greater confidence in the quality of the data, and information on sward height and cover of live and dead material is collected annually. Using a single post beyond each sampling area is less likely to alter sheep behaviour (posts have been observed to be used by sheep for scratching). Metal rods underground are less likely to be disturbed or lost, and should be easily re-located using a metal detector.

The drawback of the proposed monitoring scheme is the increased capital cost required in purchasing a metal detector and more metal pegs to mark quadrats. It would be possible to reduce the cost of the monitoring scheme by cutting down the number of communities sampled.

The cost of carrying out a monitoring scheme with well-defined aims is considerable. It must be remembered that research and monitoring studies are conducted in a world constrained by budgets. It is recommended that in future, the same amount of time is spent answering more focussed questions, with an appreciation of the levels of change that are detectable.

4.6 CONCLUSIONS

The point quadrat method allows a characterisation of the vertical sward profile. As used in this study, the information provided on change in species abundance was limited.

Using point quadrats to determine changes in species abundance would involve recording a very large number of points, which would be time consuming. Changes in species abundance should be monitored using visual estimates of cover in many small quadrats. Carrying this out adequately would take less time than collecting the same quality of data using point quadrats.

The point quadrat method gave limited information on changes in sward height. Although the change from year-round grazing to off-wintering was a considerable alteration of management, there have been only limited changes in sward structure in this treatment. Limited changes have also occurred in the treatment where year-round grazing has been continued. The change from year-round grazing to the ungrazed treatment has however had a considerable impact on sward structure, with increased sward height. Levels of dead standing material increased in all communities and treatments, a result attributed to observer error. A more suitable monitoring regime, based on taking sward heights and using visual estimates of percentage cover, is proposed.